Arsenic Contamination in Bangladesh and West Bengal

HCMG 868: Private Sector Participation in Global Health Development

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Contents

Abstract

Global water contamination is one of the main issues of concern facing the developing world in the 21st century. While bacterial water contamination is the leading cause of death and disease around the world, secondary contaminants such as arsenic, fluoride, and other heavy metals are areas of concern because of the negative health consequences that they have on the human body. In Bangladesh and West Bengal, India, waterborne illness was one of the main health concerns due to immediate complications such as diarrhea, which influenced high mortality rates among the young and the old. As a result, one of the solutions to solving the issue of bacterial contamination in surface water was to dig tube wells, which gave local communities access to ground water. Over time, it was discovered that arsenic in the ground water was the cause of diseases such as cardiovascular diseases, developmental abnormalities, neurologic and neurobehavioral disorders, diabetes, hearing loss, hematological disorders, and various types of cancer. Chronic exposure to arsenic can also cause various types of skin lesions and disease states like melanosis, leucomelanosis, and keratosis. In total, there are 120 million people at risk for arsenic toxicity in Bangladesh and West Bengal. This paper seeks to give a brief overview of the history of arsenic contamination in Bangladesh and West Bengal, to examine the current methods that address arsenic contamination in these areas, to propose and adapt the utilization of technologies for arsenic detection and remediation according to local community needs, to highlight the roles and responsibilities of the many stakeholders involved that are being fulfilled and that also have yet to be fulfilled, and last but not least, to recommend specific actions for the primary stakeholders involved.

The Global Water Contamination Problem

Global Water Contamination: A Severe Issue

Global water contamination remains one of the most serious health issues facing the developing world. Despite remarkable advancements in technology, policy, and development, over one billion people around the world lack access to a clean water source. Water contamination remains the leading cause of death and disease around the world, killing more than 14,000 people each day (1). Even in developed regions – where access is taken for granted – water infrastructure and regulations are increasingly outdated and inadequate.

Arsenic Contamination

While waterborne illness remains one of the main health concerns in the developing world, other secondary contaminants such as arsenic, fluoride, and many other heavy metals have emerged as health problems because of their deleterious effects on the body. Many of these contaminants are left unaddressed because eradicating microbial waterborne illness remains a greater priority and because the symptoms from secondary contaminants are less immediate.

Attention to arsenic is important due to the sheer magnitude of people drinking from sources potentially contaminated with the metal. Arsenic is widely distributed throughout the earth's crust. It occurs in water naturally through the dissolution of minerals and ores, but also can also be introduced to water through industrial effluents. Arsenic concentrations around the world vary as a function of the ecology and topology of the region; Thailand, Taiwan, and China in Asia have higher levels of arsenic, as does Argentina and Chile in South America. In the United States, the Gulf Coast has higher levels of arsenic (2; 3). But perhaps the most well-known location of naturally high arsenic is in India and Bangladesh. The World Health Organization's (WHO) benchmark concentration for arsenic in drinking water is 10 parts per billion (ppb), but many wells in Bangladesh measure above 50 ppb (4).

Furthermore, the story behind arsenic contamination in West Bengal and Bangladesh is remarkable. Arsenic became a significant health problem because of the introduction of shallow wells by aid organizations working to limit chances for microbial illness. This ironic phenomenon occurred most notably in the Ganges Delta. Additionally, farming practices such as irrigation pumping can alter groundwater flow through the aquifer and further introduce arsenic to the water (5).

Diseases Caused by Arsenic Contamination

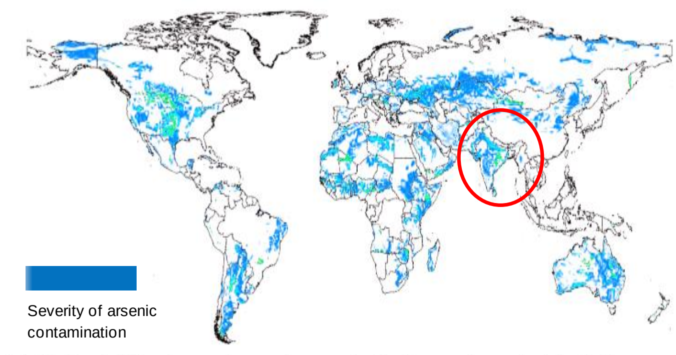

Figure 1. Extent of Arsenic Contamination Globally (30)

Arsenic is a poisonous metalloid. Arsenic toxicity in humans typically occurs from the ingestion of arsenic in food and drinking water, though it can also occur via dermal or parenteral routes. In Bangladesh, the source of groundwater contamination comes from the 8.6 million tube wells that have been drilled in Bangladesh during the past 40 years (6; 7). While research shows that the amount of arsenic in crops – such as uncooked wheat and corn harvested in contaminated areas – is negligible, the consumption of arsenic from foods cooked using contaminated water or food made from livestock consuming contaminated drinking water can occur and cause adverse health effects (8). While many are at risk for arsenic poisoning, the adverse health effects of arsenic also depend on a combination of factors, such as dose, duration of exposure, and the nutrition status of the exposed population (9). From this data, it has been estimated that up to 75 million people in Bangladesh and 45 million in West Bengal may be at risk from effects of arsenic poisoning (6).

Exposure to arsenic induces a number of different diseases, such as cardiovascular diseases, developmental abnormalities, neurologic and neurobehavioral disorders, diabetes, hearing loss, hematological disorders, and various types of cancer (10). Most commonly, chronic exposure to arsenic causes various types of skin lesions and disease states like melanosis, leucomelanosis, and keratosis (9). As arsenic and arsenic-containing compounds are human carcinogens, arsenic toxicity has also induced cancers that involve the skin, lungs, bladder, kidneys, liver, and colon (9; 10).

Arsenic Contamination in Bangladesh and West Bengal

The water contamination problem in Bangladesh and West Bengal presents a remarkable case study where successes in eliminating waterborne illness have, in fact, prompted concerns or even introduced secondary contaminants. Despite arsenic contamination being the one of the most significant public health issues in both Bangladesh and West Bengal, it has to date been inadequately addressed.

Addressing Waterborne Illness

Figure 2. Tube Well in Bangladesh

With an alarming number of Bangladeshis suffering from complications due to fecal coliform and *E. Coli* in their drinking water, the Bangladeshi government in the 1970 began a massive movement to construct tube wells to transition its population towards using groundwater in the 1970's. Since that time, 8.6 million tube wells were constructed (7), and now 97% of the country now uses groundwater as their main source of drinking water. In 1970 to 1975, the infant mortality rate in Bangladesh was 148 out of 1000 live births, of which about 50% were caused by diarrheal disease from bacterially contaminated drinking water. In 2000 to 2005, the infant mortality rate decreased to 59 per 1000 live births, in part due to the provision of tube wells (6). Thus, in Bangladesh, measures to combat waterborne illnesses caused by bacterially contaminated surface water have been largely successful.

Arsenic: Potential Mass Poisoning

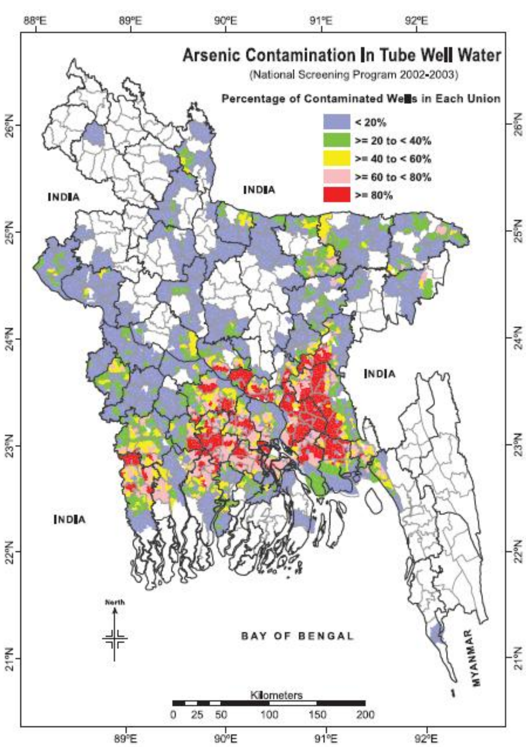

Figure 3. Concentrations of Arsenic in Bangladeshi Tube Wells (29).

Arsenic contamination slowly emerged as a problem, as it was first detected in tube wells in 1993. Today, as many as 75 million people in Bangladesh are at risk as a consequence of contamination, with an additional 45 million in West Bengal at risk (11; 12). Attempts to address the issue of arsenic contamination in Bangladesh, however, have been muted, if not unsuccessful. This is because arsenic contamination remains a secondary and largely invisible issue – diseases stemming from *chronic* exposure to arsenic develop over the long term and are not immediate concerns. Consequently, public response has continued to focus on the primary concern of common waterborne illnesses.

Awareness of the Issue

Because the problem of arsenic contamination was identified in Bangladesh only recently in 1993, large field studies and attempts at collecting data have only begun in the early 2000s. Multiple large-scale research studies and analyses have been performed to get a sense of the magnitude of the issue based on levels of arsenic in drinking wells. Recent data shows that 59 out of 64 districts in Bangladesh, for example, have levels of arsenic in their wells above 10 ppb, which is the WHO international standard for what is considered the limit for acceptable levels of arsenic. Furthermore, 43 out of 64 districts have levels above 50 ppb, which is often considered an acceptable limit within Bangladesh and India. While these studies do provide valuable data, there is uncertainty over how accurate and reliable the numbers are for the long term. International aid agencies including UNICEF, the WHO, and the World Bank, decided together to survey areas of Bangladesh and West Bengal using field kits to test tube wells, and utilized this method to test over a million wells in the 2000s (11). However, follow up and more precise studies have shown that these methods were not necessarily accurate, and many may have been mislabeled. In addition, it is likely that arsenic levels are changing over time and international aid agencies may not be willing to do multiple follow-up studies using field kits as frequently as is necessary. Thus, current methods at identifying levels of arsenic are insufficient to really gain a sense of the issue's magnitude, and they are quite costly as well. Ideally, there needs to be a more sustainable, locally implemented easy and cheap way to identify contamination in the water and then peg certain wells as safe or unsafe (4).

It is important for outside researchers and other stakeholders, both national and international, to have a consistent sense of the magnitude of arsenic contamination. However, perhaps even more important to the issue is increasing the level of awareness in the local people and villages of the areas of Bangladesh and West Bengal. According to Dr. Dipankar Chakraborti, a scientist, researcher, and expert on the issue at the School of Environmental Science at Jadavpur University, some of the biggest outstanding issues in providing a feasible solution to the arsenic contamination problem revolve around the lack of awareness in the people. Many people in villages in West Bengal either do not know of the problem, or hear about the issue and automatically assume their water is unsafe to drink (when in reality, it very well may be). When emergency field surveying does take place, it is necessary to couple these efforts to "education and awareness campaigns to assure that all individuals in affected regions understand the danger and source of arsenic as well as what can be done to avoid exposure," according to Chakraborti. Lack of understanding on the issue could actually have severe affects—for example, some villagers understand that their water is contaminated, and thus boil

their water before drinking it. While this may be suitable for bacterial contaminants, boiling off arsenic contaminated water increases the concentration of arsenic. In addition, many villagers attribute skin lesions that result from arsenic contamination to other causes, and tend to quarantine or avoid those affected believing it to be a contagious disease (13). This leads to a large number of social effects that arsenic contamination can have due to lack of awareness and understanding. Death of parents or elders causes many children and families to go into deeper poverty, and patients are often considered social outcasts and are heavily avoided. The effects are particularly bad for women—they are often considered unmarriageable, leading to further psychosocial problems for them and their families (4).

Current Methods to Address Arsenic Contamination

Given the alarm of arsenic contamination and a lack of awareness from its stakeholders, a discussion of methods to address arsenic contamination and their efficacy is necessary.

Finding Alternative Sources of Drinking Water

The preferred method for responding to contamination is to discontinue use and switch to a source free of contamination. In the case of arsenic, wells drilled to deeper aquifers may be free of contamination, though monitoring to ensure no seepage occurs is recommended. If funding for the more expensive deep well is not available, or if deeper aquifers are also contaminated, then walking to a more distant well or paying for delivery is recommended. Surface sources when available are likely to be free of arsenic, but surface water is susceptible to microbial contamination and thus must be treated to be potable.

In the case of West Bengal, it is the intention of the government to provide access by constructing large pipeline networks to route treated surface water to rural areas. While this is a valid strategy given the ample supply of such water in the region, it is popularly viewed by the population and NGO's in the region to be just another bloated and ultimately ineffective government program. The story is similar in other affected regions, with many communities left to their own devices to monitor and maintain their water sources. Given this, it is sometimes very inconvenient to seek out a more distant clean and reliable water supply (Table 1).

Table 1. Change in Time to Fetch Water

	Average time per trip (minutes)	Average total time per day (minutes)
Now	14	41 (range: 10 – 200)
Before	7	27 (range: 5 – 180)
Increase in time	7	14 (30 for those whose time increased)

Summaries of available switching options for surface water are as follows (Table 2) (14):

Table 2. Summary of Responses to Arsenic Contamination Based on Surface Water

Operational Responses	Advantages	Disadvantages
Pond sand filter	Technically easy to implement	• Poor bacteriological water quality • Low service level • Complaints about the taste of water • Selected pond sand filter should be used only for drinking water
Rainwater harvesting	Technically easy to implement	• Poor bacteriological water quality • Low service level • In some regions, cannot provide water for the entire year • Complaints about the taste of water • Can only be a partial solution in areas with prolonged dry season
Piped water supply	Adequate water quality when treatments carried out correctly Sustainable source of supply	• High level of skill necessary for design and construction • Issues of operation and maintenance and management should be considered • Other issues include affordability and system coverage

Removing Arsenic from the Groundwater

In instances where switching to an uncontaminated source is not viable, a variety of technologies exist to directly remove arsenic from existing water sources. Commonly used methods include filtration by chemical precipitation or filtration by oxidation. In chemical precipitation, coagulants such as aluminum and iron salts precipitate arsenic, which can then be physically cleaned from the water. In oxidation, oxidants such as free chlorine, ozone, permanganate, hypochlorite, and Fenton reagent (H_2O_2/Fe^{2+}) can be used to extract arsenic from drinking water onto a column of such absorbents. In either case, filtration could involve using water filters at drinking water treatment plants or at each individual household source (11).

Technologies for Arsenic Removal

Table 3. Summary of Technologies for Arsenic Removal

Technology	Removal Efficiency As (III)	Removal Efficiency As (V)
Coagulation with iron salts	++	+++
Coagulation with alum	●	+++
Lime softening	+	+++
Ion exchange resins	●	+++
Activated alumins	+/++	+++
Membrane methods	●/+++	+++
Fe·Mn oxidation	?	+/++/+++
Porous media sorbents (iron oxide coated sand, greensand, etc.)	+/++	++/+++
In situ immobilization	++	+++

Key:
+++ Consistently >90% removal
++ Generally 60 – 90% removal
\+ Generally 30 – 60% removal
● <30% removal
? Insufficient information

Given these available technologies (Table 3), the removal of arsenic from a contaminated source is possible, but not perfected. The most comprehensive methods, such as reverse osmosis membranes are costly and wasteful of both energy and water. More affordable techniques such as ion exchange resins require chemical pretreatment to effectively absorb all forms of arsenic. Even the most resilient and cost effective technique of absorption columns represents a compromise between cost and effectiveness. Very cheap absorbents such as alumina oxide are partially effective, especially when used with high iron water,

but they may not ensure removal below the global standard. More specialized absorbent media, such as nanoscale iron oxide based ArsenX produced in Pennsylvania have been validated in the field as more effective; however, their cost will remain prohibitive until local production is possible. Maintenance for most technologies is affordable though outside assistance for capital installation is often needed and education on the need for remediation to begin with is sparse. Ultimately, the largest barriers to expanded remediation are social rather than technical considerations, though new technologies can still have a dramatic impact on the global community's ability to understand and combat the arsenic problem.

Remediation Case Study: AMAL Filter

In the West Bengal region of India, there are significant levels of Arsenic contamination. Despite government promises for pipelines of treated surface water, most communities are responsible for their own water supply or rely on government wells. One project which has had a beneficial impact on the issue in the region began with a donation of ten thousand dollars in 1996 by international NGO Water for People to Bengal Engineering and Science University to support development of an appropriate arsenic removal device. The result a year later was the AMAL filter (Figure 4), a community based filter that uses activated alumina as the media which removes arsenic. The filter works by taking the water that is pumped from a tube well, and letting it flow through a tall packed bed filter, three feet of which is a column of activated alumina. The arsenic attaches to the surface of the activated alumina through ion exchange. It should also be noted that iron also bonds to the surface of activated alumina. This is important because there is very high iron content in the ground water that, once oxidized, bonds with arsenic. Much of this is caught by the sand filter top section of the column and the rest is caught by the alumina column. High iron content, therefore, if given the chance to oxidize, serves as a first stage of filtration. The presence of this secondary absorbent in the water naturally is the key to the viability of alumina based filters for the region. Activated alumina absorbent is inexpensive and readily available though not effective enough for standalone use. This is an example of an appropriate method being identified from a toolset of available technologies to fit the needs of a particular region.

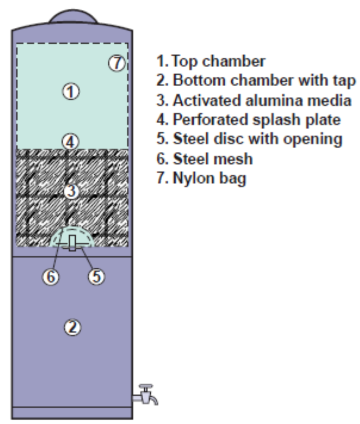

Figure 4. The AMAL filter is a device that uses activated alumina to removed arsenic. It was developed for community-wide usage.

The media used in the filter is made in the region so it does not need to be imported or shipped. The physical filter is made locally. After the filter is set up, a care taker tends to the day to day upkeep and safety of the filter, and the community collects money to pay for any filter maintenance that is required. The filter is backwashed daily for most filters. Every four weeks, the filtered water is sampled and tested for arsenic concentration. These tests will show when the filter needs to be regenerated, which involves the activated alumina being siphoned out, sent to the regeneration center where it goes through an acid base wash to disassociate attached arsenic, before it is placed back in a filter. The media is expected to have a lifetime of 5 regenerations. See Figure 5Figure 10 in the Appendix for a visual of the arsenic remediation life cycle.

The AMAL filter has been deployed with initial success. There are currently over 140 installed units, each serving a range of about 80-400 families each. Variants have been produced to work with electric pumps, storage tanks, and most recently a larger scale version for installation at schools. Children can be particularly vulnerable to arsenic exposure and school filters allow for intervention targeting this group. Additionally as awareness remains one of the largest challenges with arsenic contamination, the school installations provide an opportunity to educate children on the risks and over time influence communities to take action to improve their community water supplies (15; 16).

Implementation: Attempts at Arsenic Detection and Remediation

As stated earlier, sporadic field tests carried about by private sector organizations have been conducted in Bangladesh and West Bengal to measure concentrations of arsenic, yet such tests only target tube wells and are most likely to *underestimate* concentrations of arsenic. Furthermore, because each of these organizations acts independently, there is no sustainable effort to take these measurements periodically, and aggregate data exists, but is sparse.

With respect to find alternate sources of water, efforts to identify contaminated wells have only exacerbated the situation. Attempts to label tube wells with concentrations of arsenic above 50 ppb as contaminated, for example, only confused village communities, who ignored the labels because the alternate options to obtaining water were too cumbersome, or who stopped using tube wells *entirely*, even though some of them were clean. Village communities who are simply recommended to change their water supplies nevertheless lack the understanding as to *why* they need to change their water supply, thus any response is negligible.

With respect to remediation, there have been private sector efforts to implement these technologies. UNDP and WHO have funded the installation of Arsenic Removal Plants (ARPs) through for-profit companies and universities such as Pal Trockner (PT) and Bengal

Engineering Science University (BESU). However, a recent study of the efficacy of ARPs has revealed that 35% have already become defunct, and only 11% substantially decrease arsenic levels (8; 17). Funding is also a problem. More generally, any assistance from international aid organizations has been channeled elsewhere; according to Dr. Dipankar Chakraborti, "Bangladesh took $50M from the World Bank in 1998 and they're not using that money… 50% has gone to foreign consultants; 20% goes to government overhead… 5% of money going to actual field. If you want to really solve the problem, you must change this outlook." (12)

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Despite attempts to detect for and remediate arsenic in the groundwater in Bangladesh and West Bengal, there simply lacks any organization or sustainability in such efforts. What is needed is an *implementable system* for arsenic detection and remediation.

Stakeholder Analysis

While solutions for arsenic detection and remediation not only have been developed but also have been tested and demonstrated as feasible, *the inability* to address arsenic contamination in not only the developing world, but in the developed world is a consequence of stakeholder inabilities to fulfill roles and duties for which they are responsible. In order to develop *an implementable system* for arsenic detection and remediation, it is important to identify the stakeholders, describe their requisite roles and duties, and note whether those roles or duties are being satisfied.

Stakeholder Frameworks

The following map (Figure 5) identifies major stakeholders along the following dimensions: (1) level of on-the-ground involvement, ranging from internal (direct, on-the-ground involvement) to external (peripheral involvement), (2) extent to which arsenic contamination affects *them*, ranging from superficially affected to directly affected, and (3) relative importance within the system (represented by icon size):

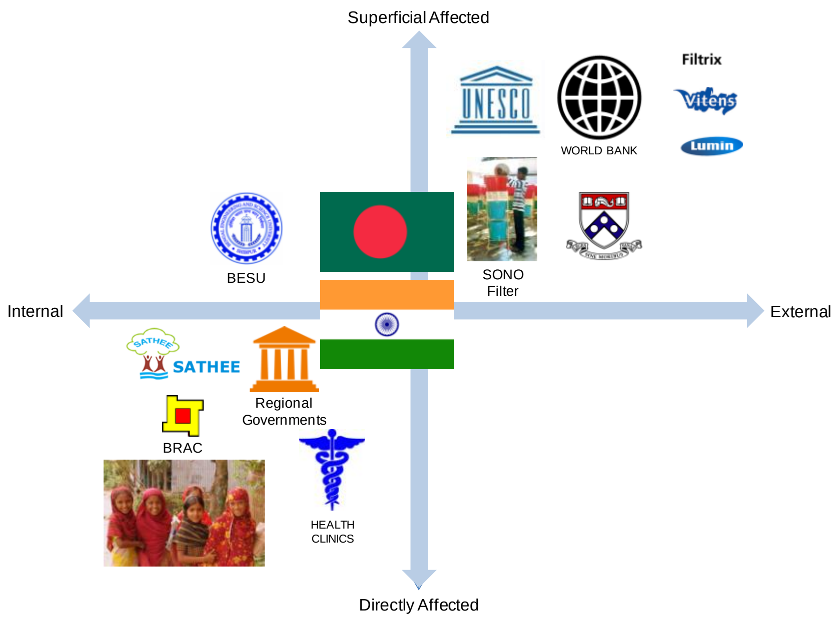


Figure 5. The Stakeholder Map for Arsenic Remediation.

Using this map we clustered the stakeholders into six major categories:

Table 4. Six Major Stakeholder Categories

Six Major Stakeholder Categories
1. International Aid Organizations 2. International Institutions 3. Public Sector Entities 4. Local Public/Private Institutions 5. Regional Non-Profit Development Organizations 6. Village Communities and People

In addition, each of the stakeholders plays a role in the following sequence of events that describes a working system for arsenic detection and remediation:

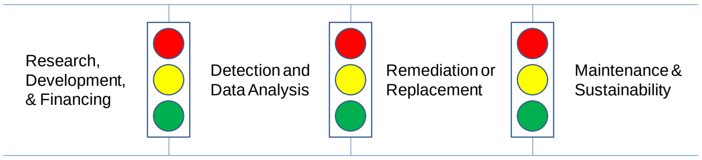


Figure 6. The "value chain" for arsenic detection and remediation, generalized in this sequence.

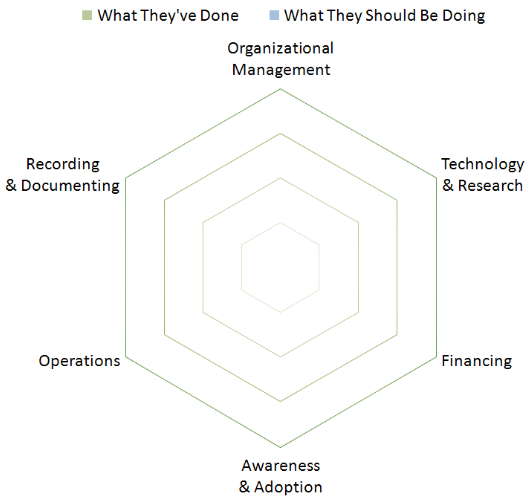


Figure 7. Stakeholder analysis radial map.

To evaluate the stakeholders, we introduce a framework that identifies the six most important duties and roles in a working system for arsenic detection and remediation. For a given stakeholder category, we loosely quantified the extent to which they are responsible for each duty or role (what they should be doing) – and whether they perform it acceptably (what they've done). The results were depicted on a radial map, where a larger radius represents greater responsibility for a particular duty or role. Gaps in the radial map represent weaknesses in the stakeholders' ability to perform those duties or roles.

The six duties and roles we chose for our framework are:

Table 5. Stakeholder Duties and Roles

Six Duties and Roles	Description
1. Organizational Management	Enabling stakeholders to perform their respective roles
2. Technology & Research	Developing the products and methods that can detect arsenic in the field and remediate contaminated water sources
3. Financing	Paying for the system
4. Awareness & Adoption	Educating community members on the dangers of arsenic contamination and how to implement a system of detection and remediation
5. Operations	Doing the actual testing and filtering in the field
6. Recording and Documenting	Gathering aggregate data from field tests to determine policy, and later on, whether a system for detection and remediation is actually working

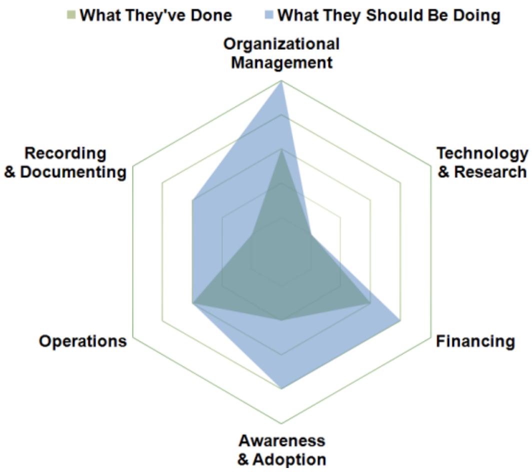
These frameworks allow us to evaluate stakeholders' roles in a working system for arsenic detection and remediation. For each of the stakeholder categories, we will also recommend ways in which stakeholders can better perform their respective duties and roles.

Stakeholder Categories

International Aid Organizations

Members: World Health Organization, World Bank, UN Dev. Organizations (UNESCO, UNICEF, UNDP)

Key Examples: WHO, UNICEF



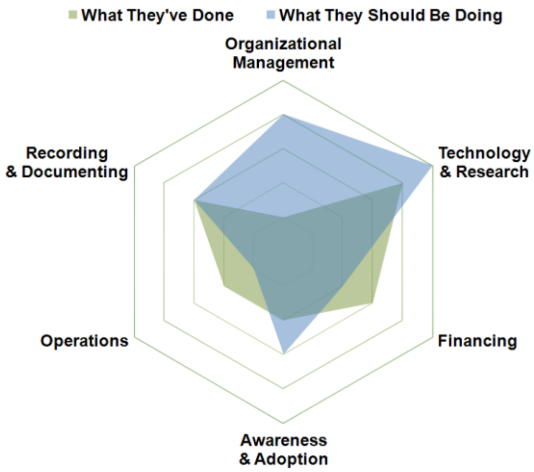
What They Have Been Doing: UNICEF is in charge of leading the arsenic response program in Bangladesh. They worked with the government's Department of Public Health Engineering and other local non-profit organizations to survey tube wells in the early 2000s. Out of 5 million wells that were tested, 1.5 million were "UNICEF" supported. They created a National Arsenic Communication Strategy and Campaign, which was focused on developing mass media and communication tools for the people in affected communities. They had testers of tube wells educate fellow well users while they were testing, and paint the wells based on if they were considered safe or unsafe to drink from. There were two main programs facilitated by UNICEF, SHEWA-B and DART. SHEWA-B was planned along with DFID to increase awareness and install new water points, while DART was planned along with CIDA to facilitate, through the Government of Bangladesh, the placement of arsenic removal plants. International Aid organizations including the World Bank, WHO, and UNICEF used colorimetric field kits to test for arsenic in tube wells, and follow up studies with more precise testing techniques showed that many of the wells they had tested were not necessarily marked correctly as "safe wells." There is no private testing agency, and while these tests may provide valuable data, they are not always accurate or reliable because arsenic content will change over time. It may be unlikely that international aid organizations are willing to test so frequently. And while some organizations, such as the WHO and UNDP, have implemented arsenic removal plants in some regions of Bangladesh and West Bengal, maintenance of these plants has been very poor, and eventually they become futile.

What They Should Be Doing: While aid organizations may be incredibly helpful in managing large conglomerates of smaller non-profits, working a bit with local governments and organizations, and developing organized plans for tackling the issue, they do not necessarily have the capacity for high maintenance, monitoring, and operations of the solutions they implement. They do have an important role in financing, and they need to continue to develop high awareness problems for national governments as well as for the global community. When they do give money to governments and local organizations, they need to make sure their money is going to the right places. Often times, local governments end up spending the money on overhead and only a very small proportion goes to the field. In addition, they need to have a role in management of monitoring and surveillance. It is not enough to just put an Arsenic Removal Plant in a community—they need to be sure that local people or organizations are constantly following up and maintaining the plant. Ultimately, International Aid organizations biggest role in the Arsenic Problem should be understanding the big picture, and working with local governments to increase awareness and adoption within the countries and globally, channel money to appropriate places, and make sure constant monitoring of solutions is occurring. Ultimately, the aid organizations themselves do not need to engage much in research, in sending people into the field to actually test water or be involved in maintenance, or in increasing awareness on the community or village level.

International Institutions

Members: VITENS, Norit Filtrix, British Geological Survey, Lehigh University, University of Pennsylvania, Harvard University, WAGTech, HACH, LAMOTTE, Industrial Test Systems

Key Players: Industrial Test Systems, WagTech, Harvard University



What they are doing: A main role of international institutions not involved in "aid" has been the research and development of products that could detect or remediate arsenic contamination. While there are existing technologies and testing kits available through private companies including WagTech, and Industrial Test Systems (18), universities are today pursuing new research projects to develop easier, cost effective solutions that can be more efficiently implemented in developing communities. Available products include the Arsenator, a kit being used by UNICEF and produced by Wagtech. Several companies such as Industrial Test Systems offer field-testing kits based on the Gutzeit method of chemically reducing arsenic to arsine gas which then reacts with a testing strip. Once purchased for around $150 refills of reagents can be purchased for around $1/test making this the most cost-effective option available but still too costly to enable the scale of testing and monitoring needed at current levels of awareness and investment.

Competitions for scientific innovation and sustainability such as the Grainger Competition of 2005 have been successful in incentivizing research towards new solutions. These competitions spur research and help to narrow the realm of possible new techniques to a small number of high potential winners which are worth investing for field trials. In field trials time is taken to understand the perspective of local communities and adapt the product as necessary for complete local use. The degree to which this last step of validating research with appropriate local partners occurs varies greatly. Success stories include the SONO filter, developed by a George Mason professor and subsequently adapted and implemented by NGO's in Bangladesh with several iterations of refinement following initial field trials. Other efforts by international agents, however, have been terribly misdirected. Case in point funds of nearly thirty million dollars donated through the World Bank are widely reported to have been mismanaged and often spent on international consultants with limited continuing value (12).

What they should be doing: Action by international institutions should be guided by the research and publications of local organizations conducting research on the issue and in the best position to provide perspective on what will be readily adopted and appropriate. Overall there needs to be more communication between the research being done in the field and the development sphere in the private sector. Information should be aggregated by international aid and policy organizations and made available in an actionable manner to institutions developing technology which may be effective in addressing related challenges. Doing isolated research studies on populations in Bangladesh is not enough—there needs to be constant follow up and that research should be translated into clear specifications which are published to institutions and companies able to take action. It's important for projects in the field to be collaboration between those with expertise in emerging technologies and those who understand the market demand and local community's ability to manage those technologies.

International stakeholders have attempted to implement arsenic removal plants, but in many cases the lack of a responsible party for maintenance has resulted in these plants being abandoned. For such installations to be successful they must be integrated with existing or new educational campaigns which communicate to users the importance of taking ownership over the treatment plant.

A particular area where the innovation and discipline of the private sector can be valuable is in the development of improved methods for detecting the presence of arsenic in the field, and perhaps even removing it from the environment. Case in point is the emerging venture Lumen. A global team of researchers based at the University of Edinburgh, University of Pennsylvania, and Imperial College are developing a novel form of contamination test based on synthetic bacteria engineered to be sensitive to various levels of contamination.

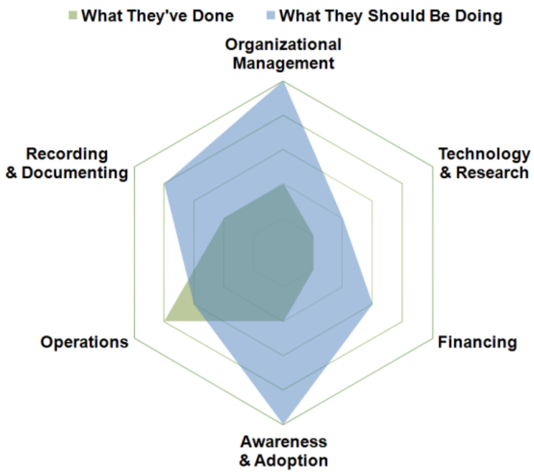
The work of global academic institutions can also be critical in characterizing and analyzing the global challenges associated with contamination. For example, at Harvard University, a group of scientists and researchers is working on documenting a holistic picture of arsenic contamination, including the social issues that play a large role in how local communities respond to and manage the problem.

In summary, research universities and the private sector must be informed by regional organizations and global policy institutions to set clear directions for work. Once measures are implemented additional partners or measures are needed to ensure that maintenance and follow-up is carried out.

Public Sector Entities

Members: Bangladesh, West Bengal (India)

Key Examples: Bangladeshi government, Government of West Bengal (India)



What they have been doing:

Bangladesh

Between 1993 and 1995, the Department of Public Health Engineering (DPHE) found that 1.2 million tube wells out of 3 to 4 million were contaminated with arsenic in Bangladesh. In 1999, the British Geological Survey and DPHE identified that the groundwater of 60 survey districts out of 64 were contaminated with arsenic. A survey from the School of Environmental Studies (SOES) and Dhaka Community Hospital source reported that 47 districts are contaminated with arsenic. According to this source of the DPHE, many hand-pumped tube wells are now inoperative. As a result, the government has provided alternative arrangements for safe drinking water in affected areas; however, these arrangements only reach a few families. While the government encourages the use of surface water and water from wells, locals find it more convenient to use tube wells (19).

The World Bank is currently coordinating an integrated response to the arsenic crisis, and through the government of Bangladesh, is supporting the Bangladesh Arsenic-Mitigation Water Supply Project (BAMWSP). An important component of the BAMWSP is community-based, demand driven projects, in which community members play an active role in choosing and implementing solutions to the problems of arsenic contamination at their respective sites (20). However, instead of devising practical methods of groundwater remediation, most studies and actions have focused on testing tube well water for arsenic. Recently, in the coastal areas, the DPHE-Danida water supply and sanitation project has begun to supply safe water outlets for the poor, and management of the project has been entrusted with the local communities.

West Bengal

Currently, 50% of the districts in the state of West Bengal in India are exposed to arsenic contamination in their tube wells, which has resulted in many people being diagnosed with symptoms of arsenic poisoning (21). There are no studies that address the economic dimension to welfare loss and the associated costs and benefits of arsenic contamination and removal.

In the past, the West Bengal government was slow to respond to the researchers who were trying to inform them of the issue of arsenic contamination. The Calcutta Municipal Corporation (CMC) and government of West Bengal did not acknowledge the issue of arsenic contamination in tube wells until 1996, and several governmental reports were issued that downplayed the gravity of the situation and deflated the numbers of people affected by arsenic toxicity. Unfortunately, arsenic treatment units that were placed in villages are frequently out of order and many are unable to reduce arsenic below the WHO recommended value of 0.05 mg. The West Bengal government has been notified by researchers that it is the massive extraction of groundwater for irrigation that is causing arsenic to enter into the water, yet the government continues to provide deeper tube wells for drinking water. According to Dr. Chakraborti, highly effective technologies may not succeed in rural areas unless there is an honest will of the

politicians, the technology suits the rural circumstances, and the rural mass accepts the technology (12). The development and implementation of these kinds of technology are only possible when bureaucratic and technological efforts are also coordinated with village-level participation and understanding.

What they should be doing:

Bangladesh

The Bangladeshi government, WHO, and other international organizations have yet to consider other ways in which arsenic may have deleterious effects on human health, such as the possible health effect of arsenic-contaminated irrigation water on the livestock. In general, more detailed studies should be conducted on potential health problems originating from irrigated soils, water, and plants. Additionally, inexpensive and efficient uses of methods for the removal of arsenic from drinking water need to be adopted. Researchers have also stated that the government, along with non-governmental social welfare groups, will need to take the lead in raising awareness about the hazards of all kinds of contaminants, particularly the issue of arsenic contamination in groundwater. More specifically, it is important for the government to filter these responsibilities down to schools and villages to educate the public on the arsenic issue. In the short run, the provision of safe drinking water in arsenic-affected areas is the most immediate concern. Treatment or development of alternative safe water sources can form part of the long-term investment in improved water supplies, though local communities would be unlikely to pay for arsenic removal or less convenient alternative supplies than their own hand pumps. Because the government of Bangladesh will be unlikely to be able to afford the cost of providing treatment or alternative resources, the strategy should be moved towards developing systems that will address the issue of convenience of access and sustainability, in which government funding for capital and fixed costs can be maintained or reduced. While government policies advocate involvement of the private sector and government agencies frequently act as intermediaries who opt to involve the private sector when it suits them, the private sector should be encouraged to respond directly to consumer needs instead.

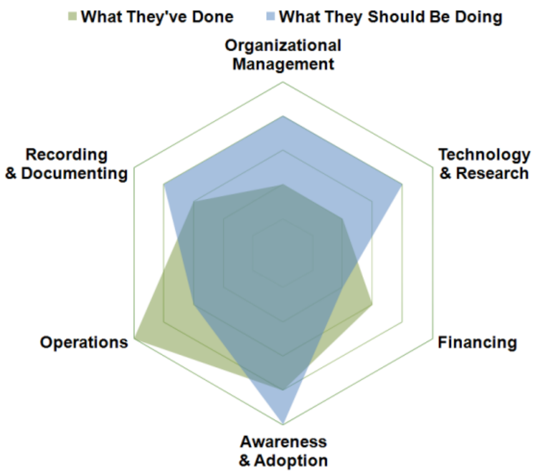
West Bengal

The West Bengal government has not responded to the issue of arsenic contamination well in the past. The most important step that the government must take is to acknowledge the issue of arsenic contamination and increase awareness among villages. If the government is to continue using groundwater for irrigation, then effective watershed management is essential to preventing more people from being affected by arsenic toxicity. In addition, the many surface water resources in the rivers, wetlands, flooded river basins, and oxbow lakes should be better utilized for drinking water. Watershed management and villager participation are essential in mobilizing communities to utilize these large water resources.

Local Public/Private Institutions

Members: Health Clinics, Major Hospitals, Universities

Key Examples: Bengal Engineering and Science University, Jadavpur University (Environmental Studies)



What They Have Been Doing: Given the inefficiency and distrust of government actions, local public and private institutions have sometimes been the only actors with knowledge of and influence in rural communities sufficient to operationally carry out educational, research, and remediation activities. Local universities have technical proficiency and deep understanding of their local region, making them ideal for conducting field research to characterize the severity of the problem and effectiveness of existing solutions. Institutions such as Jadavpur University have carried out such efforts. They report their results in regional conferences and international publications, raising awareness and guiding efforts to address the problem with a local context that is often missing. Beyond research, local organizations should *implement* sustainable solutions. In isolated cases, organizations have already done a good job taking action using the insight gained by such ground research. The development of the AMAL filter at Bengal Engineering and Science University in Kolkata is an example. With an NGO grant, the University designed within a year a filter unit which adapted existing remediation technologies to a device appropriate for the high iron water of their region. The filter was implemented successfully in over a hundred communities.

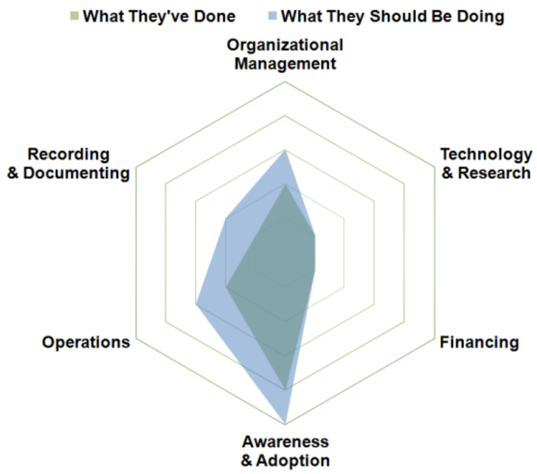
What They Should be Doing: The effectiveness of research efforts by Jadavpur and BESU demonstrate the potential impact local public institutions can have on increasing knowledge of the problem and communicating the perspective of affected communities to the broader global community. The AMAL filter project and similar efforts demonstrate the prospective role of local institutions in developing appropriate technology solutions. This effort is, unfortunately, the exception rather than the rule, with most other technology being developed by parties far less knowledgeable of the conditions facing the populations making use of the kit. Even in the BESU case, however, success at scaling relies upon their ability to transfer the effort from the control of time-strapped university faculty to a separate private or NGO organization dedicated to delivering the solution to the population. Transferring the technology to a dedicated organization can provide sustainability and the ability to scale the effort. An example of this is operation of the remediation plant for saturated absorption media in West Bengal. This critical maintenance step was performed for several years under the management of the University, but just this year a private company has taken over this role. The company will provide monthly water testing and annual media regeneration at prices affordable to the communities who have set aside funds to maintain their remediation systems. With this new entity, the former employees feel ownership and have financial incentive to scale the effort to help additional communities. The existing installations by the University and support from NGO's provide a pool of guaranteed customers, making it easy for businesses to charge affordable prices to communities while profiting enough to expand.

The recommended role for local public/private institutions is first to translate observations and community relationships into insight guiding the actions of other stakeholders who can provide the funding and expertise to jumpstart a solution. Second, local organizations should at the end of the day be the entities carrying out action in a sustainable manner.

Regional Non-Profit Development Organizations

Members: Shibpur Association for Technological Humanitarian and Environmental Endeavours (SATHEE), BRAC, IRC, International Institute of Bengal Basin (IIBB)

Key Examples: SATHEE, International Institute of Bengal Basin



What They Have Been Doing: Shibpur Association for Technological Humanitarian and Environmental Endeavours (SATHEE) is a non-governmental organization that works extensively in India. SATHEE focuses its activities on providing safe drinking water, facilitating proper sanitation systems, promoting and educating local communities about basic hygiene practices, and promoting the adoption of modern technology to provide cost-effective water safety measures for community use. Upon discovering that the delta region of West Bengal has greatly suffered from arsenic contamination, SATHEE has taken measures to remediate the issue in this region by installing arsenic removal units in 156 communities and 38 schools. In addition, SATHEE has partnered with local government authorities and Bengal Engineering and Science University (BESU), respectively, in providing filters and more arsenic removal units in the western parts of West Bengal and the rural areas in the state of Uttar Pradesh in India.

The International Institute of Bengal Basin (IIBB) is a nonprofit organization that works on environmental and ecological issues in the Bengal Basin. IIBB recruits various experts to assist in finding solutions to the many problems that exist in India and Bangladesh. IIBB also offers pro bono environmental consulting services to industries, landowners, citizens, nonprofit organizations, and political institutions in the region. Through the services that IIBB offers, the organization also educates communities about arsenic contamination in the Bengal Basin.

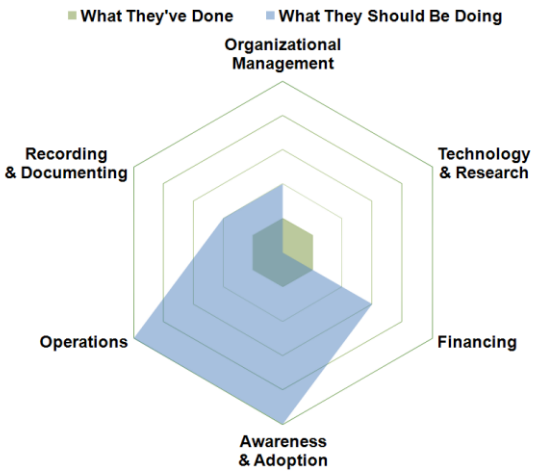
The work of regional non-profit organizations varies from one organization to another. Overall, these organizations are proactive in their role of awareness and adoption. While some groups are more well-connected than others, regional non-profits are doing their best to alleviate issues of arsenic contamination by collaborating with international aid organizations and institutions to implement the testing and filtering of arsenic in local communities.

What They Should Be Doing: The highest priority of regional non-profit development organizations should be awareness and adoption. Non-profit development organizations, non-governmental social welfare groups, and other similar organizations should partner with local governments to educate communities about the issue of arsenic contamination in tube wells and the negative health consequences of arsenic toxicity that result from arsenic contamination in food, water, and the environment. In addition, members of these regional organizations may serve well as community health workers, who would be able to work alongside researchers and government officials in showing local communities how to conduct testing of arsenic and filtering in the field. Another important role that regional non-profits should fulfill is to serve as liaisons between the local communities and outside organizations, such as international aid organizations, international institutions, and even local private institutions.

Village Communities and People

Members: Communities in developing countries directly affected by arsenic contamination

Key Examples: Chalk-Khorgachi in Baduria Block of North 24 Parganas West Bengal; Char-Ruppur village, Iswardi Thana, Pabna, Bangladesh; and many, many others



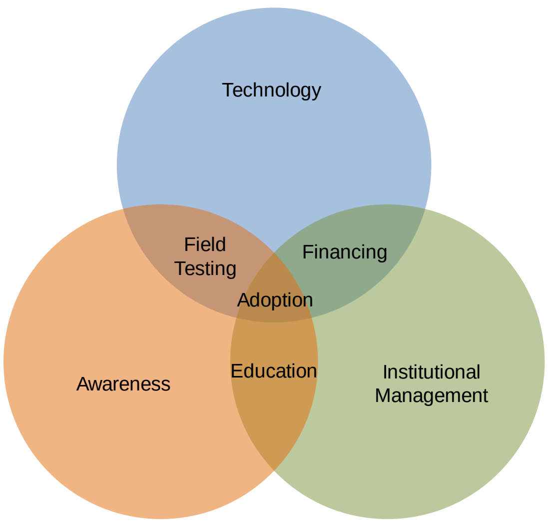
What They Have Been Doing: These communities have continued to consume water that may be contaminated with arsenic. They contract diseases and illnesses as a consequence, but oftentimes are unaware that it is the arsenic in the water that is responsible – some, in fact, believe it to be a religious matter instead of a problem in the water. Because of this lack of understanding they generally have failed to address the arsenic contamination situation.

What They Should Be Doing: Adoption is critically important, so communities must play an important, if not leading role in performing field tests for arsenic and afterwards remediating their own water sources via one of the several filtration methods. They need to help fundraise for these tests and filters insofar as it involves their own water sources, i.e. they need to pay or at least contribute to the payment for their own point-of-use field tests. Most importantly, they need to be *aware* of the situation – the community leaders need to work with the local, regional, and national governments to educate their members of the harms of arsenic so they can collectively work on a solution that fits the community (for example, if that means walking further to a clean source, organizing the community such that fewer trips need to be made).

Recommendations

The aforementioned stakeholder analyses provided a rigorous set of recommendations for all stakeholders to improve their abilities to contribute to the solution, or at least begin to address the problems, of arsenic contamination in Bangladesh and West Bengal. In the following section, we prioritize and categorize such recommendations using a framework inspired by Dr. Arun Deb, a leading researcher on arsenic contamination. These recommendations highlight the power possessed by the private sector to help create an implementable and sustainable system for arsenic detection and remediation.

Design of a Successful System: The Three Pillars



To frame our recommendations to lay the groundwork of an implementable system for arsenic detection and remediation, we will refer to Dr. Arun Deb's "Three Pillars", a framework based on what he identified as the most significant problems facing arsenic contamination (22). He noted three particular factors: (1) the lack of technology that can be used sustainably by communities without jeopardizing their financial well-being, (2) the lack of awareness of the problem from all stakeholders but most importantly from the communities most directly affected, and (3) the lack of institutional management to help organize how arsenic should be detected in the fields and how such sources should be remediated should they have concentrations of arsenic above 50 ppb (right now, universities and private enterprises simply parachute into Bangladesh and West Bengal, conduct a test, publish data, and move on – creating significant waste and redundancy. Our recommendations will focus on how technology and awareness can be addressed immediately, and how effective institutional management will also help such recommendations be effective.

Technology: Field Testing and Data Analysis

The largest barriers to solving the arsenic problem are not technological in nature but social and political. This being said, proper development and implementation of technology can secure or break the success of efforts to eliminate exposure to dangerous water contaminants such as arsenic. Perhaps the most common cause of failure of technology is the lack of perspective and thought by those involved into the reality of circumstances for those who will be

expected to purchase and use it. This can be addressed by a better coordination among involved stakeholders to share information and guide promising technology from the laboratory bench to meaningful assistance to those impacted by the contamination.

Fundamental technology research can best be accomplished by Universities, including both global institutions such as the University of Pennsylvania or IITs and smaller regional technical centers such as Bengal Engineering and Science University. To guide their efforts global or regional aid organizations could publish requests for capability, similar to requests for proposals common in industry which would help to convey the needs of the field in the form of technical capability required. For instance when UNICEF realizes that field agents are spending too much time transporting samples they could publish a short request document outlining their ideal concept for a new field test method. Research teams intending similar work could then be motivated to move forward with urgency and better perspective on the nature of the needs of those in the field.

Technology related to water contamination can be broken into the categories of detection, remediation, and reporting. In each of these areas there are technology milestones which would be desired to most effectively support a coordinated global response as well as individual action by local communities.

Detection

Detection of arsenic is possible today through both laboratory and field methods, however, millions of sources in vulnerable regions remain untested. Addressing this requires fresh political urgency driven by both international pressure and by grassroots educational efforts raising awareness of the issue and available remediation options. One method for such grassroots participation is a business model similar to cell phone recharge kiosks where local entrepreneurs distribute and/or administer tests. To enable this distributed model of testing a new form of field test would be required which is self-contained, inexpensive, reliable, and extremely simple to use. While existing field tests come close, they are mistrusted by many and contain or emit materials such as mercury and arsine gas which represent environmental and occupational hazards respectively. The ideal testing device would be one which could be distributed inexpensively to designated members of a water committee in a community without extensive training or concern for the disposal of reagents.

Reporting

The impact of even an ideal contamination testing method is limited if it is not paired with technology and policy for collecting, distributing, and storing this data effectively to increase

awareness and drive informed action. There is extensive opportunity for improvement on this front as existing data collection systems are informal and disaggregated where they exist at all. Quick progress can be made by adapting existing technologies developed for similar purposes. Case in point would be adaptation of a reporting software platform developed at the University of Cape Town which allows field agents to report the results of contamination tests done in the field using simple SMS text messages which are received by the system and recorded to a central database. Over time collection of such information will result in a clear regional perspective on the quality of water in the region. When contacted, researchers on this project expressed enthusiasm for partnering to implement their system within regions such as West Bengal and Bangladesh to begin gathering arsenic data in a distributed manner which can then be aggregated regionally and cross-referenced with health data to clarify the disease burden associated with contamination and strengthen the argument for renewed investment and action.

Remediation

Remediation technologies capable of reducing even severe contamination levels below the stringent WHO global health standard of 10ppb exist today, but deploying the most effective technologies such as reverse osmosis membranes is often not a viable option due to their cost of installation and maintenance. Arriving at a workable solution thus becomes a balancing act of identifying which of the remaining options are appropriate for the region given composition of the water (i.e. dissolved iron levels) and other factors such as availability and affordability of expertise and spare components. The cheapest of the absorption options are often not capable of truly reaching the global standard. Regions such as West Bengal compromise with a regional limit at five times the global recommendation. More effective proprietary options exist but are not cost effective. In the near-term, establishment of local production capacity for such media is recommended. Following a similar strategy to that pioneered by Novavax for vaccine production, the improved media can be introduced in developing regions which need it most at the same time as it is made available to US household filters by partnering with appropriate local manufacturers. In the long term emerging research in nanotechnology will enable new media with surface area exponentially higher than current options. These new technologies will eventually make viable inexpensive household filters which can be used for extended periods before becoming saturated by the contaminant.

Awareness and Adoption: Education for Everyone, Especially Village Communities

To quote Dr. Chakraborti, "People are not interested because they aren't educated. You must educate the people, let them know about the problem, and until you do this, you cannot solve the problem."

Currently, one of the largest problems identified by many experts who have worked in the field in Bangladesh and West Bengal is the significant lack of awareness and understanding of the issue in local communities. There are varying degrees of lack of comprehension of the issue, from some communities being entirely unaware, to others who are aware but take little action to solve the problem. In addition, many communities actually drink water that is entirely safe, but hear of a water contamination problem and refuse to drink their water not knowing whether or not it is safe. Many people also are preoccupied dealing with infectious diseases and other prominent health problems, and thus have not focused their attention on arsenic contamination as it is only a recently identified issue (13; 12).

> *People are not interested because they aren't educated. You must educate the people, let them know about the problem, and until you do this, you cannot solve the problem.* (12)

The most sustainable and obvious solution to the arsenic contamination problem and providing access to clean water actually falls on first educating the local people and then providing them insights into action they can take to combat the issue. It is important that communities understand that arsenic is not the same kind of contaminant as bacterial infection, and thus traditional methods such as boiling water cannot be utilized to remediate the problem. Communities should know which wells in their local areas are safe or unsafe, and they should take initiative to undergo "well switching" if they are using an unsafe well. As new technologies and filtration or removal techniques emerge, it should be the local communities and people who are trained to use and maintain them on a daily or weekly basis.

One way to pilot the use of technology and give responsibility to local people is to pilot programs in schools. According to Dr. Prabodh Gupta, who has extensive experience with global health development in India and who is Director of Cytopathology at the Hospital of the University of Pennsylvania, utilizing schools for new projects or trials is one of the most effective ways to educate local community members because youth tend to be passionate and active in engaging fellow peers. In addition, teachers serve as good mentors and have responsibility in the schools to make sure students are following protocol (23). The WHO actually has a program entitled the Global School Health Initiative, which was launched in the mid 1990s with the goal of fostering health education and awareness in schools at the local, regional, and

national level. This has been an effective way in building awareness in communities in China and Vietnam, for it is a bottom up approach that builds local capacity (24).

Another way to build local capacity and foster awareness and comprehension of the problem is to recruit young and passionate arsenicosis patients to work on combating the problem. Patients of arsenic contamination are still often isolated in their communities because of their large skin lesions that other community members attribute to an infectious disease or perhaps the result of sins and religious forces (11). However, bringing these people to the forefront of the fight against arsenic contamination and showing how they combat the problem through finding and drinking safe water and improved nutrition will be a valuable education tool. Fieldwork performed by Dr. Dipankar Chakraborti has shown multiple examples of such patients, who have recovered from their contamination because of early improved sanitation, and who are now actively working in nearby universities and research groups as well as within their own communities to help remediate the problem (13).

Institutional Management: Managing All of the Clutter

Ultimately, technology and awareness cannot be implemented without the proper organizational management at the local, regional, national, and international levels. We offer tactical recommendations for organizational management with respect to the two recommendations we have already made.

Tactical recommendations for Technology

The existence of multiple, and more importantly, *redundant* studies investigating arsenic remediation in Bangladesh and West-Bengal suggests that (1) there is no formal organization over such data and (2) there is no effort to provide sustainable studies or assess the situation over the long term. What is needed is not only the gathering, but also *sharing* of information, between investigators and private sector enterprises. Additionally, the universities that develop remediation technology and successfully test it in the field should adopt a system of *technology transfer*, to allow private sector enterprises to implement these new technologies in the field. There needs to be a flow of information: information on contamination, information on disease burden, information on field testing strategies and best practices (Figure 8).

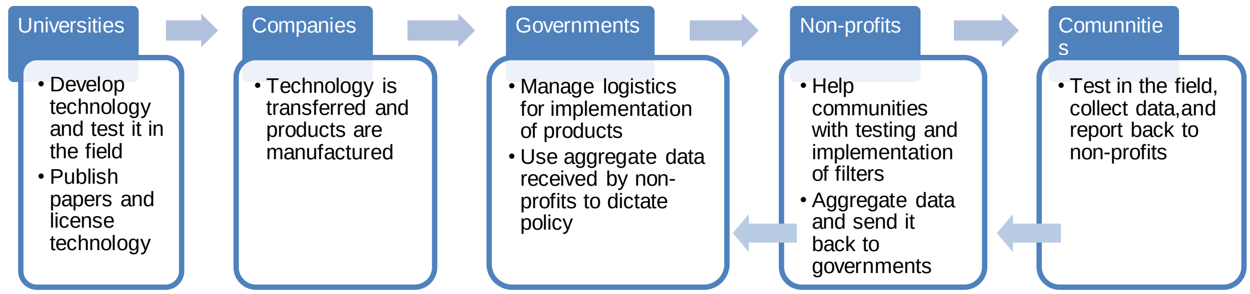


Figure 8. Flow of Information from "External Stakeholders" to "Internal Stakeholders" on the ground.

Thus, we recommend the formation of partnerships between universities and for-profit or non-profit teams on the ground. This includes regional non-profit organizations, micro entrepreneurship, and similar stakeholders as defined on the stakeholder map. Furthermore, we recommend that governments enforce mandatory public-private-partnerships (PPP's), to provide mandatory contracts to these for-profit enterprises to implement such technology in the field. Specifically, when money is given to a regional government, part of that money needs to be privatized; this creates an industry, ultimately transitioning to an independent system by which arsenic can be tested for in the field, documented, and ultimately remediated by paying for a system sold by a private sector enterprise.

We can look to the efforts by the Canadian Institutes for Health Research at the University of British Columbia and UBC's University-Industry Liaison Office as a case study in which technology transfer in the form global access licenses between universities and the biotechnology industry benefits *both* the developed and developing world. In this case, an oral amphotericin B (AmpB) formulation in preclinical studies could one day provide the developing world with a treatment for leishmaniasis. Such an oral treatment would be manufactured by biotechnology companies and then distributed by them to communities, with no need for a clinic visit. Because they had an industry partner who shared their views on global stewardship, UBC created an agreement allowing them to deliver such technology to the developing world (25).

Lastly, to continue to promote the research and development of arsenic detection and remediation technologies, international aid organizations and public sector entities should continue to award grants and prizes to technologies with disruptive capability. A notable example is the 2007 Grainger challenge Prize for Sustainability by the National Academy of Engineering, awarded to Abul Hussam, professor at George Mason University, for the Sono arsenic filter. Hussam will spend 70% of the $1M prize to implement the filter in Bangladesh (26).

Tactical Recommendations for Awareness and Adoption

With respect to awareness and adoption, private sector entities need to work with local non-profits and private/public sector organizations to develop curricula and marketing

campaigns to educate their communities about the harms of arsenic remediation. They need to do so in an organized way – and a successful approach is to develop a system that targets schools. For example, the global school health initiative by the World Bank engages students at local schoolhouses and informs them of arsenic contamination early on (24). The World Bank needs to partner with local governments to ensure that such education is incorporated into the mandatory curricula.

Another approach has been the "road show" approach by the Department of Health Education-Danida water supply and sanitation project (DPHE-Danida), which entrusts education to the local communities by providing traveling shows and exhibitions that draw their interest. These shows are, unfortunately, limited in their utility. Irrespective of the approach, each of these methods has limited scope unless, again, there is a formation of a public-private partnership (PPP) that allows international aid organizations such as the WHO to develop strong curricula, have governments mandate such education and have local non-profits educate communities as mandated by the governments and using the curricula from WHO and others.

Lastly, there needs to be an incentive for *communities* to readily adopt these lesson plans on arsenic contamination – hitherto communities have demonstrated a lack of understanding with arsenic contamination, and this is reflected in their actions. Thus, there needs to be the formation of *community councils* that organizes how arsenic is to be tested in the field, how technologies are going to be implemented, and how the curricula can be tough. The PPP's stated above can developed standard format for a community council, as well as incentives for such councils, for example providing them with a pool of money that they manage for these initiatives that is contingent upon milestones such as the delivery of data to local NGOs, installation of arsenic filters, teaching of curricula, and routine maintenance collection.

Despite these tactical recommendations for better implementation of technology and awareness for arsenic contamination, more significant and widespread recommendations must be made – for example, the creation of an international entity that draws stronger attention to arsenic contamination. However, these recommendations provide solutions for the "lowest-hanging fruit" – i.e., the most immediate and tractable issues within arsenic contamination that need to be addressed. Only after answering these issues can a stronger push to address arsenic contamination be made.

Summary

Arsenic contamination is increasingly becoming one of the most severe global water contamination issues, with the worst cases occurring in areas of West Bengal and Bangladesh. There are multiple projects being undertaken to help remediate and understand the problem that are currently still in the research phase. Moving forward, it is vital that improvements in technologies, awareness and adoption, and institutional management take place so the poisoning does not continue to affect millions. There are various groups of stakeholders who have all had some hand in the remediation efforts thus far, but these groups need to understand where they can best fit in and improve. Key players who will have to take on a much larger role in the process of remediation are local governments and local communities, who should both have responsibility of increasing awareness, maintaining current technologies, and understanding how to best utilize current resources. It is important for international aid organizations to continue funding efforts as well as management and encouragement of local governments to increase their responsibility of the issue. In addition, both international and local institutions should continue to engage in research to develop innovative and easy to use products that are a good fit for local use in both identifying arsenic levels and/or removing or filtering arsenic for those communities who have no alternative water source. In fact, a study conducted at Reading University and University College London noted that at a sufficiently low price point, arsenic remediation could even create significant value and revenue for the community to which it directly affects (27). A combination of efforts, and an emphasis on both public-private and international-local partnerships will be the key agent of change in the arsenic contamination issue.

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Primary Interviews List

We would like to thank the following individuals for their information and insight in the interviews we conducted with them:

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- Dipankar Chakraborti, Ph.D.
- Arun Deb, Ph.D.
- Prabodh Gupta, M.D.
- Kanwarjit Singh, M.D., M.B.A.
- Robert Giegengack, Ph.D.

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Appendix

Figure 9. Images of Skin Lesions and Other Ailments Suspected to be the Consequence of Chronic Exposure to Arsenic (13)

Table 6. Summary of Technologies for Arsenic Removal

Technology	Removal Efficiency As (III)	As (V)	Institutional Experience and Issues
Coagulation with iron salts	++	+++	Well proven at central level, piloted at community and household levels. Phosphate and silicate may reduce arsenic removal rates. Generates arsenic-rich sludge. Relatively inexpensive.
Coagulation with alum	●	+++	Proven at central level, piloted at household levels. Phosphate and silicate may reduce arsenic removal rates. Optimal over a relatively narrow pH range. Generates arsenic-rich sludge. Relatively inexpensive.
Lime softening	+	+++	Proven effective in laboratories and at pilot scale. Efficiency of this chemical process should be largely independent of scale. Chiefly seen in central systems in conjunction with water softening. Disadvantages include extreme pH and large volume of waste generated. Relatively inexpensive, but more expensive than coagulation with iron salts or alum because of larger doses required, and waste handling.
Ion exchange resins	●	+++	Pilot scale in central and household systems, mostly in industrialized countries. Interference from sulfate and TDS. High adsorption capacity, but long-term performance of regenerated media needs documentation. Waters rich in iron and manganese may require pre-treatment to prevent media clogging. Moderately expensive. Regeneration produces arsenic-rich brine.
Activated alumins	+/++	+++	Pilot scale in community and household systems, in industrialized and developing countries. Arsenite removal is poorly understood, but capacity is much less for arsenate. Regeneration requires strong acid and base, and produces arsenic-rich waste. Long-term performance of regenerated media needs documentation. Waters rich in iron and manganese may require pre-treatment to prevent media clogging. Moderately expensive.
Membrane methods	●/+++	+++	Shown effective in laboratory studies in industrialized countries. Research needed on removal of arsenite, and efficiency at high recovery rates, especially with low-pressure membranes. Pre-treatment usually required. Relatively expensive, especially if operated at high pressures.
Fe·Mn oxidation	?	+/++/+++	Small-scale application in central systems, limited studies in community and household levels. More research needed on which hydrochemical conditions are conducive for good arsenic removal. Inexpensive.
Porous media sorbents (iron oxide coated sand, greensand, etc.)	+/++	++/+++	Shown effective in laboratory studies in industrialized and developing countries. Need to be evaluated under different environmental conditions, and in field settings. Simple media are inexpensive, advanced media can be relatively expensive.
In situ immobilization	++	+++	Very limited experience. Long-term sustainability and other effects of chemical injection not well documented. Major advantage is no arsenic-rich wastes are generated at the surface; major disadvantage is the possibility of aquifer clogging. Should be relatively inexpensive.

Key:

	+++	Consistently >90% removal
	++	Generally 60 – 90% removal
	+	Generally 30 – 60% removal
	●	<30% removal
	?	Insufficient information

Figure 10. The Life Cycle of Arsenic Remediation